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Corrosion Monitoring in the Oil Pipeline Industry

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***Abstract*—The paper presents current knowledge on corrosion and its monitoring of internal and external corrosion phenomena in the transmission and distribution pipelines in petroleum industry. The conjoint use of in-line inspection techniques (ILI) and side stream monitoring techniques are highly favoured in order to eliminate catastrophic failures as a result of internal pipeline corrosion problems. External corrosion phenomena in pipelines can be adequately monitored through the deployment of electrode potential measurements using suitable reference electrodes. Improvements in pipeline coatings applications have been highlighted and the often neglected chromating procedure prior to coating application has been addressed with Nigerian patent, NG/P/2013/755 of April, 2014.**

Keywords – corrosion monitoring; in-line inspection; pipeline coatings; functionalised chromate pretreatment coating.

I. INTRODUCTION

Although C-Mn steel is generally the most economic material for the construction of pipelines, other specifications are available for use in harsh environments. Pipelines are assemblies of shorter lengths of pipes that are welded together. The most widely used standard for specifying pipe is the international standard API 5L/ISO 3183 (2007), although the construction code DNV-OS-F101 (2007) is also being used by some operators. Pipelines are important part of energy gathering and transportation infrastructure which are of immense importance to national economies. In examining the condition of a pipeline, In-Line Inspection (ILI) utilizing various Non-Destructive Testing (NDT) methods have been described essential tools in establishing quality management programs that are useful in establishment of safe and cost effective operation of pipelines[1].Predominantly, in-line inspection techniques detect sizes, locate flaws and defects within pipe walls [2]. ILI tools are varied and could perform e functions of inspection tools, cleaning tool and/or gauge tools [3]. Failures of pipelines as a result of corrosion and other physical means are rampant especially in African countries where it has been alleged to be poverty induced, malicious third party incursions on pipelines carrying petroleum products. Third party incursions can be monitored using various, recently developed fibre optics techniques. The prevention of failures as a result of corrosion, which is a natural phenomenon, and a continued safe operation of these pipelines are of immense interest to the operators and both oil and non-oil producing nations at large. For internal corrosion of pipelines, the primary method of preventing failure is by inspection using “Smart pigging” or “Intelligent pigging” to locate and repair critical flaws prior to becoming a threat. However, for one reason or another, some pipelines are unpiggable. Aside from this, the cost of carrying out inspection can be very prohibitive as a result of additional costs due to preparation for pigging. Some, which are not limited to these, are: costs of provision for pig launchers and catchers etc. The ability of this technique to find corrosion flaws with size of about 10% of the pipe wall thickness is doubtful. Although flaws larger than 10% can be detected, however of greater concern is the “find it and fix it” procedure which when employed at the expense of corrosion prevention through corrosion monitoring and complimentary strategies, leads eventually to increases in costs of pipeline repairs and replacements. As regards, the corrosion of the external surfaces of pipelines, various time tested procedures and techniques such as the conjoint use of coatings and cathodic protection have provided eminent protection in various environments in which pipelines are deployed. Monitoring for corrosion control in this instance involves monitoring the effectiveness of the cathodic protection system. Thus, this review takes a look at internal and external corrosion problems/monitoring of pipelines deployed in the oil transmission and distribution network.

II. CORROSION PROBLEMS IN PIPELINES

A. Internal Corrosion of Pipelines

For corrosion to occur there must be an electrolyte, water in this instance, contaminated or otherwise with various ionic species, are regarded as the corrodants. The water must wet the wall of the pipe. Once this occurs, corrosion will take place at a rate which depends on the physical and chemical properties of the water as well as microbial counts in addition to presence of sediments and oxygen. A large number of pipelines have failed as a result of significant corrosion caused by insignificant quantity of water accumulation in low spots at low velocities when water content of oil/product is as low as 0.1%. Water usually accumulates at low spots which are typically inaccessible, such as under rivers and streams and the low water contents of pipeline crudes and products make it nearly impossible to obtain samples for testing purposes. Internal corrosion can lead to production reduction as corrosion by-products accumulate in the pipeline and, in the event of a through-wall failure, can cause extensive hazard to people and damage to assets and the environment [4]. There are various corrosion models in use which directly estimate internal corrosion of pipelines. However, these models are limited in scope and to the authors knowledge none has yet been put in the market place which can accurately model pitting and microbial corrosion as well as corrosion under sediments. These are the major corrosion problems which challenge the crude and products transmission pipelines. These corrosion mechanisms can be very rapid such that they can threaten pipelines with leaks within a few months if not controlled. Although these corrosion models are very useful in predicting where and how fast corrosion will occur in pipelines at about 80% confidence level, their limitations as mentioned above make complimentary tools for assessing internal corrosion in-situ by direct assessment using ‘Side Stream Monitoring’ techniques inevitable. The models in question include the use of phase equilibria to forecast the location of condensing and liquid water and hydraulic models predict the effect of velocities on corrosion. Other models include Shell’s in-house HYDROCOR, CASSANDRA (BP) and other commercial packages like Honneywell/Intercorr Predict 4.0 and 5, NORSOK M-560. These models are conceptually based around the works of De-Waard and Milliams [5] with some modifications. However, the two commonly used models are BP CASSANDRA and NORSOK M-560 which are regarded as freeware. The side stream monitoring technique has been successfully and accurately employed in assessing the insidious corrosion problems of the pipeline industry, such as pitting, microbial and corrosion under sediments. This direct monitoring system assesses corrosion in an on-line manner and can detect upsets and changes with time due to corrosion inhibitor/biocide effectiveness and bacterial growth [6]. The performance of the side stream monitor is dependent on removal of fluids from the pipeline of interest. The water component is then tested for its corrosivity using various methods. Thus, sediments which may have accumulated in the test chamber can be employed for measurements of corrosion using suitable techniques and test pieces to explore corrosion activities under the sediments. [7]. Test coupons can also be exposed in the vapour phase in the oil layer to monitor corrosion activities in this phase as well. Thus on-line measurements using Linear Polarisation Resistance (LPR), Galvanic probes, and Electrical Resistance (ER) probes will allow for the development of bacterial corrosion to be observed in-situ [8]. In addition, upsets, which give rapid indication of changes in the system, can be followed. Also water sampling will give results for bacterial counts, the presence of slimes, sediments analysis, corrosion inhibitor residuals and oxygen content. Thus by measuring actual corrosion rates in a system, direct accurate assessments are achieved which will prevent surprises and reduce risks which will result in better allocation of resources. Other less robust monitoring instruments do exist. These include a range of thickness gauges [9]. While a model measures thickness of pipeline walls and can differentiate between external and internal corrosion, another type, such as pin-point Bolt-on Sensor sleeve is available in the market [10]. However, the confidence level of data obtained from the use of these is low compared to the side stream monitoring technique.

B. External corrosion of pipelines

The use of good integrity coatings for adequate protection of pipelines has been in use for ages. Corrosion reducing techniques are no limited to application of good quality coatings such as application of fusion bonded and liquid applied epoxy coatings and polyethylene slip-liners, of utmost importance is the selection of suitable materials tat are fit for purpose [11]. However, pipeline coatings have undergone dramatic technological changes over the decades which can be adequately described as starting from asphalts, then bituminous coatings to poly ethylene (PE) and now fusion bonded epoxy (FBE) coatings and most recent developments with the use of thermal sprayed metallic coatings such as Aluminum and Zinc [12]. Fusion-bonded epoxy coatings were introduced in 1959 and were first used as an exterior pipe coating in 1961 but currently are the coatings most commonly used for new installations of large diameter pipelines because of their ease of application and durability [13]. They are however gaining popularity in submerged offshore applications, including some offshore pipelines. The metallic coatings offer the benefits of low cost with excellent corrosion protection over a wide range of temperature and conditions. In addition, they provide a measure of cathodic protection although, they still require supplemental anodes etc. These are still in their infancies and we expect to witness continued progress. Currently, coating technology in the oil and gas industry has come a long way. The product evolution for protection of steel pipes has gradually shifted from field-applied asphalt and coal tar-based materials to the currently used high-tech, field-applied and plant-applied coatings. The main generic types of pipeline coatings in use today include coal tar enamel, polymeric tapes, fusion-bonded epoxy (FBE), spray-applied liquid coatings, and two- and three-layer polyolefin coatings. It is of tat that some coatings are often over coated with abrasion-resistant overlay (ARO). These are employed in the protection of the main corrosion control coating layer which obviously perform the functions of tie coatings which binds the underlay and ARO when the pipe is installed via directional drilling as witnessed in coatings applied for road or river crossings [14]. Others of equal importance are coatings such as, 3-layer polypropylene (PP), 3-layer PP insulation systems and multi-layer insulated systems [15]. However, it is equally of note that performance factors of importance during selection of suitable coating materials are physical and chemical stability, resistance to soil stress, resistance to cathodic disbondment, adhesion and resistance to impact [15]. Currently, coatings are expected to perform at higher in-service operating temperatures, must not be damaged in handling, during construction or in operation by soil stress or soil movement, and must provide exceptional corrosion protection. And above all, the coatings must provide barriers to the electrolyte and protect the metal from incursions by the environment in which it is deployed [16, 17]. In addition, they must be user friendly and must be able to be applied in a mill or in the field.

Good surface preparation prior to coating application is very important in order to avoid failures in service. Time tested standard procedures include: 1. Grit blast to agreed standard such as Sa3, 2 or 1, after removal of dirt and grease; 2. Vacuum clean to remove dust; 3. Apply conversion coating with chromating solution for added corrosion protection; 4. Apply coating as per manufacturers' directions; 5. Avoid application in inclement weathers. Quality assurance procedure demands that each step conforms to standard. Do it once and do it correctly is of the essence. Often omitted by coating applicators, is the chromating step probably due to environmental reasons and concerns about marginal increase in costs at the expense of improved corrosion and coating adhesion. However with the advent of the quick drying, smart conversion coating variety, environmental issues have been reduced to the barest minimum because effluents have been eliminated. A typical example is the product from Nigerian patent, NG/P/2013/755 [18], which combines improved corrosion resistance and paint adhesion to metallic surfaces. In addition, in case of breaching of the coating to expose the substrate, corrosion inhibitors are released to stifle corrosion reactions in such regions.

The monitoring of external corrosion of pipelines can be performed by obtaining the pipeline/soil or environment potential with the use of $Cu/CuS0_4$ reference electrode or ay other suitable reference electrode. It is universally accepted and from experience in the field that, a potential reading, with respect to $Cu/CuS0_4$ reference electrode, more negative than -850mV or at least 100 mV more negative than the native (freely corroding) potential of the pipeline is indicative of no significant corrosion. In the par adventure of the presence of microbial induced corrosion (MIC) a potential of –950 mV or a shift of at least 300 mV from the freely corroding potential is recommended.

III. CONCLUSIONS

Direct, accurate measurements of internal corrosion of pipelines can be achieved by side stream monitoring technique. It measures corrosion rate in-situ with limited disruption to pipeline operations. It allows pigging to go on simultaneously. This will prevent leakage surprises, reduce risks and will result in better allocation of resources which will lead to cost reduction. Time tested corrosion monitoring of the externals of pipelines using potential measurements is important and should be performed regularly at least once in a year in order to avoid catastrophic consequences.

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